# MAIN RING RF NOTES

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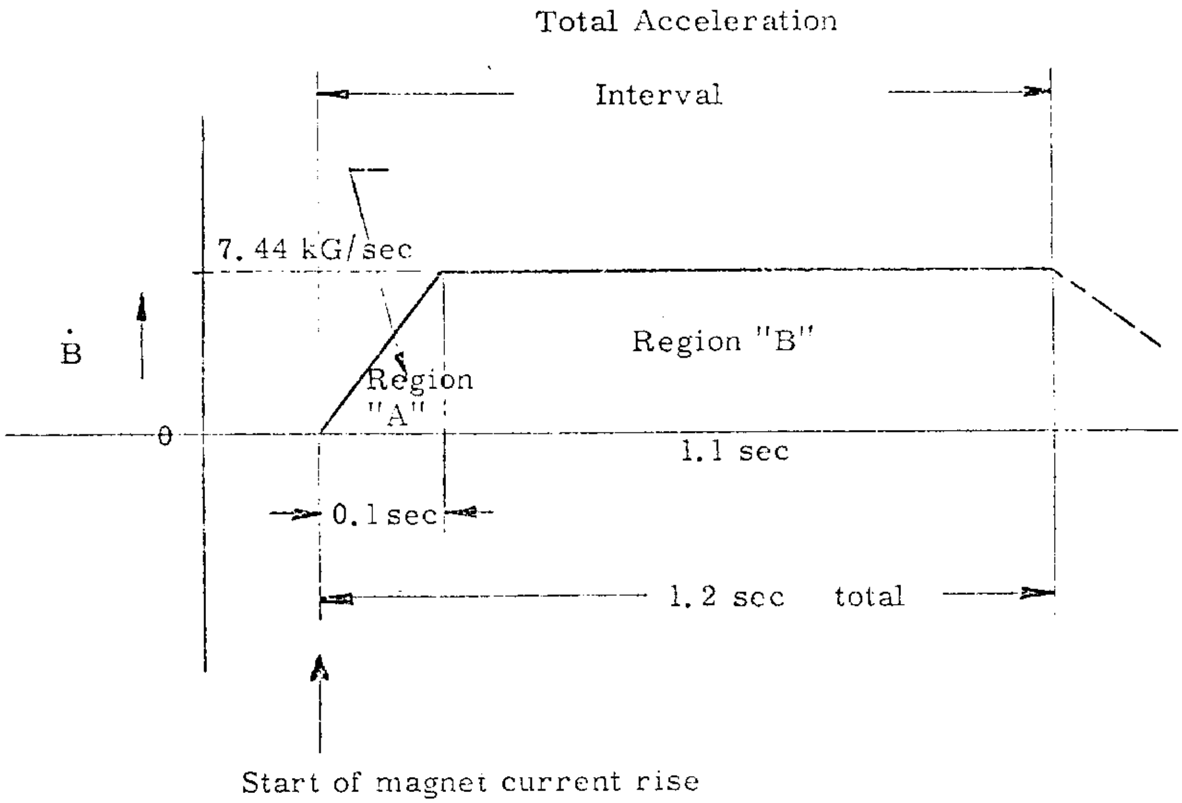
## INTRODUCTION

The idea of R. R. Wilson to use two separate rf systems, with appropriate guide field rate of change for each system, is looked into (briefly) for a ferrite-tuned system. During the first part of the guide field rise (region A), we are careful not to overload the ferrite and we achieve this result by asking at first for only a nominal rf ring voltage. Later on in the rise, we ask for full ring rf voltage, which is then tolerated by the ferrite tuner because the ferrite is heavily biased.



PROPOSAL

Let $\ddot{B}$ = constant during region "A",

wherein $\ddot{B}$ = $74.4\ \text{kG sec}^{-2}$ .

Let $\dot{B}$ = constant during region "B",

wherein $\dot{B}$ = $7.44\ \text{kG/sec}$ .

Note: Region "A" is selected as 0.1 sec for simplicity; it does appear best to make it as short as possible so that region "B" can be as long as possible--we are constraining Time "A" + Time "B" = 1.2 sec.

If $B_{inj} \approx$ 450 gauss, B at the end of 0.1 sec goes to $B_{inj} + 1/2\ \ddot{B} t^2$ $= 450 + 372 \approx 822$ gauss, so the proton energy goes roughly from 10 GeV to ~18.2 GeV; $\gamma$ increases from 11.7 to about 20.4. This increase in $\gamma$ is a factor $\frac{20.4}{11.7} \approx 1.74$ which allows a sufficient increase in cavity rf voltage but preserves the ferrite's characteristics (i.e., keeps the loss tolerable and avoids hi-flux spin-wave instabilities in the ferrite).

During region B, the guide field climbs uniformly from 822 gauss to 9,000 gauss in 1.1 sec, or $\dot{B} = \frac{9000-822}{1.1} \approx 7.44\ \text{kGsec}^{-1} = .744\ \text{T/sec}$.

Ring Voltage During Acceleration

The energy gain/particle turn is

$$eV_b = 2\pi R \rho \dot{B} e \quad .$$

From the point of view of the rf system as a voltage generator, it is convenient to call $V_b$ the "beam voltage" because the product of $V_b$ and $I_b = \frac{Ne\beta c}{2\pi R}$ is directly equal to the beam power (i.e., the power absorbed by the beam during acceleration). That is,

$$V_b I_b = \frac{d\left(\begin{smallmatrix}\text{K. E. of}\\ \text{the protons}\end{smallmatrix}\right)}{dt}\ .$$

The peak ring voltage (due to all the cavities) is

$$V_o = \frac{V_b}{\sin\phi_s}\ .$$

If we take $\phi_s = 50^o$ ($\sin\phi \approx .766$), (Note: this is somewhat less than that suggested in the talk.)

$$V_o = \frac{2\pi\rho R\dot{B}}{\sin\phi_s}$$

taking

$\rho$ = 743 meters

R = 1000 meters

$\dot{B}$ = 0.744 tesla/sec,

$$V_o = \frac{2\text{x}3.14\text{x}743\text{x}10^3\text{x}0.744}{.766} \approx 4.52 \text{ megavolts}$$

$V_b$ the "beam voltage" 3.46 megavolts

$I_b$ the beam current $= \frac{Ne\beta c}{2\pi R} \approx$ 229 milliamps

During region "B," the beam power is

$$P_b = \frac{\Delta U}{\Delta t} = \frac{Ne\Delta V}{1.1\text{sec}} = \frac{3\text{x}10^{13}\text{x}1.6\text{x}10^{-19}\text{x}(200-18.2)}{1.1} \approx 793 \text{ kW.}$$

Note: $e\Delta V$ is the energy gain/particle during region "B."

During region "A," the beam power rises linearly from zero to 793 kW.

Number of Cavities

If we allow 18 operating cavities + 3 spare cavities = 21 total, and provide for an energy loss of 50 keV in each spare cavity (the beam passes through all cavities including idle cavities), we need a total ring voltage from the 18 cavities of

$$V_{ring} = V_o + \text{Induced Voltage in idle cavities} = V_o + .15 \text{ MV.}$$

$$V_{ring} = 4.52 + 0.15 = 4.67 \text{ MV.}$$

$$\frac{V_{ring}}{18 \text{ cavities}} = \frac{4.67 \times 10^6}{18} = 260 \text{ kV peak/cavity.}$$

If we run all 21 cavities together, we need only $\frac{4.52}{18} \times 10^6 = 251$ kV peak/cavity.

Power Tube Requirements

Assuming the total beam power of 793 kW will be delivered by 18 tubes, the beam power contribution/tube is

$$\frac{793}{18} = 44 \text{ kW.}$$

Using cavities (note, however, that they contain no ferrite--it is placed in a tuner at the far end of a transmission line) like those of the LRL Design Study, and allowing for transmission line and ferrite tuner losses, we get the following additional rf power requirements:

Cavity + transmission line losses from combined shunt impedance of 0.8 megohms/cavity:

$$P_{\text{skin loss}} = \frac{V^2_{\text{cav. peak}}}{2\,R_{\text{shunt}}} = \frac{(2.6)^2 \times 10^{10}}{1.6 \times 10^6} = 42 \text{ kW/cavity}$$

The estimated ferrite loss at the worst peak (which will occur somewhere in region A) $\approx$ 22 kW per cavity tuner.

TABULATION

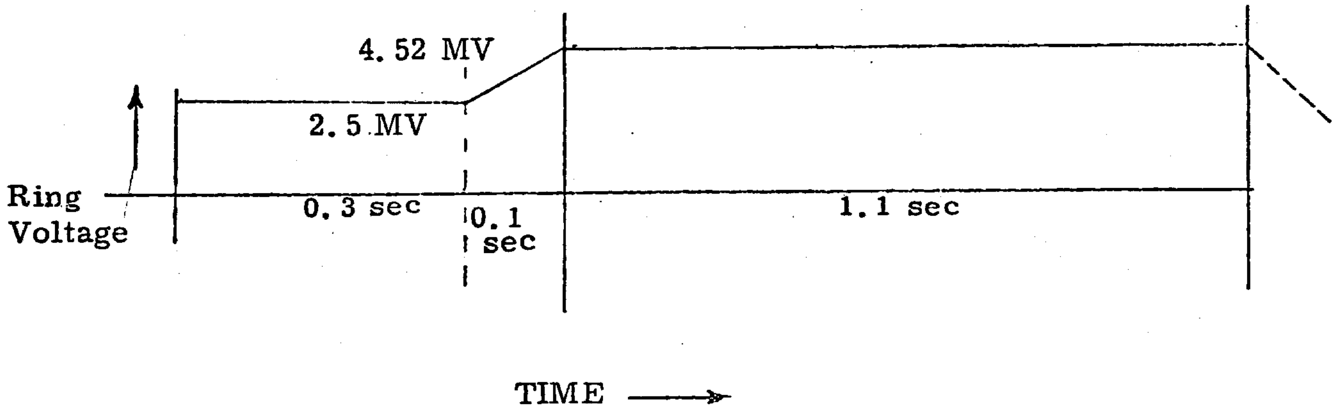
| Per Cavity if 18 on | | Total System |
|---|---|---|
| Beam power | 44 kW | 793 kW |
| Skin loss | 42 kW | 756 kW |
| Ferrite (worst peak) | 22 kW | 396 kW |
| Tube output | 108 kW | 1.945 MW Total |

## RF Power Tube

The RCA (developmental) tube A2872 would be a good choice for this application, especially because the A2872 has a low grid voltage swing requirement for driving. We need wide-band drivers to accomplish fast rf amplitude and phase control. We should, therefore, consider input requirements to the main power tube as well as output power capabilities in making a tube selection. In its price range(~$4,000), the A2872 is outstanding for low-drive requirements. (See attached data sheets for A2872 and A2873).

There are other suitable tubes, but one should anticipate paying from $2-10K for such a power tube as is needed. A (grounded-grid) triode would be cheaper than the tetrode, but the higher cost of suitable (higher power) drivers would likely offset the power tube savings.

During filling time, when the ring is a proton storage ring accepting pulse trains from the booster, one would expect to drop the ring voltage below 4.5 MV as in the Design Study. The ring voltage might look as follows:




The precise form of the voltage rise in "A" bears looking into if we want to simplify the ferrite needs as much as possible consistent with an acceptable program for $\phi_s(t)$ .

## Cavity Length and Straight Section Requirements

The Design Study cavities are 74-1/2" long and 25" in diameter. I would anticipate shortening these to 68" by slight lengthening of the internal sleeve. Twenty one (21) such cavities will occupy $\frac{21 \times 68}{12} \approx 120$ feet.

The system could be cut into three equal parts of 7 cavities each, 40 ft long. The three 40' sections could be placed in 3 of the 50' straights.

Of course, other cavity designs should be looked at, such as Matt Allen's design (SLAC $e^- - e^+$ storage ring). There are two things to keep in mind: We want a total system stored energy of 10 - 15 joules/MW and very tight coupling to the transmission line and power tube.

About the stored energy: If there is too little, the cavity phase and amplitude regulation suffers. If there is too much, the tuner is more expensive--this is wasteful. About the coupling: the matched-impedance coupling schemes which work nicely for constant loads like antennas of transmitters (or electron synchrotrons in which the loads though not constant at least vary slowly over many microseconds) are not satisfactory for modulated beam loads. Therefore, we depend on strong coupling and high standing wave ratio lines from tube to cavity.

## Remarks About $TM_{010}$ Mode Standing Wave Structures

The pure $TM_{010}$ mode has a very poor transit time factor, would require about 15 ft diameter cavities, and would occupy a prohibitive length of tunnel if we reduce the stored energy (by lowering $E_z$ ) to a value tolerable for tuning.

Inserting drift tubes solves the transit time factor but still the cavity diameter is large and the stored energy for a 150 ft-long structure at 4.5 MV is much greater than we need for beam loading transients. The excess stored energy requires correspondingly expensive tuners to handle the rf kVA.

A further modification could be to capacitively load the drift-tube gaps. If loading is carried to the point that the drift tube surface carries most of the displacement current, the cavity diameter shrinks considerably.

It is, however, now essential to divide the structure into cells and drive each cell separately if we wish to obtain the shortest length for a given overall stored energy. For, if we do not subdivide the cavity into separately-phased cells, the only possibilities are o or $\pi$ phase shift from gap to gap, requiring gaps to be $\frac{\lambda o}{2}$ .

If we perform the subdivision into separate cells (although mechanically the structure can be monolithic), the $\frac{\lambda}{2}$ restriction is lifted and the gaps can be spaced much closer than $\frac{\lambda}{2}$. Clearly, we no longer have TM but TEM; the end result of the aforementioned modifications is the proposed structure. The purpose of this exercise is to show some of the thoughts leading to the electrically separate cavity design.

## Arguments Against the Wide-Band Untuned Traveling-Wave Structure

1. Expensive in rf power cost because total input power to beam power ratio is low.
2. Tends to constrain both booster and main ring rf to high frequencies like 100-200 MHz. If one is willing to forget reason (1) above, then the structure can be built for any frequency, however low; the efficiency getting less and less as the frequency is lowered.
3. The rf phase control problem for missing bunches (fluctuating beam load) is severe, requiring wide-band modulators or wasteful dummy loads for its solution.

## Vacuum and Insulators

The cavities may as well be completely in vacuum, eliminating all ceramic insulators from the cavity proper. A feed insulator is required where each transmission line connects to its cavity, since the coax line itself should probably not be evacuated but run at normal air pressure.

Vacuum pumps can be connected directly to the cavity outer walls at intervals along the 120' of accelerating structure, pumping through a grating of slits parallel to the cavity axis (direction of rf current).

# SUPER-POWER BEAM POWER TUBE

RCA DEVELOPMENTAL TYPE NUMBER **A2873**

## PROPOSED TECHNICAL OBJECTIVE

RCA-Dev. No. A2873 will be a liquid-cooled, ceramic-metal, super-power, beam power tube for operation at frequencies up to 50 Mc/s. Ratings are proposed as an rf power amplifier in class C telegraphy service, a plate-modulated rf power amplifier in class C telephony service, an rf pulse power amplifier in class B plate-pulsed service, and a hard tube modulator in pulse power service. The A2873 will be useful in a wide variety of communications, particle-accelerator, radar, or control applications.

The high power gain and low drive voltage characteristics of the A2873 will permit the use of solid-state driver circuits to afford the advantages of increased system reliability and economical operation. The tube will also feature a multi-strand thoriated-tungsten filament for long-life expectancy.

The mechanical structure of the tube consists of a symmetrical array of unit electron-optical systems surrounding a centrally located plate. Integral water ducts to all electrode areas provide effective cooling of the tube structure.

**Useful to 50 Mc/s**

**High Gain**

**Low Drive Voltage**

**Coaxial-Electrode Structure**

**Ceramic-Metal Construction**

**Thoriated-Tungsten Filament**

**Liquid Cooled**

**500 Kilowatts CW Output at 50 Mc/s**

**1200 Kilowatts Peak Pulse Output at 50 Mc/s**

**10 Megawatts Pulse Power Output in Hard-Tube Modulator Service**

## PROPOSED GENERAL DATA

**Electrical:**

Filament, Multistrand Thoriated Tungsten:

| | | |
|---|---|---|
| Voltage (Single-phase AC or DC) | 3.9 | V |
| Current at 3.9 volts | 1700 | A |
| Starting Current | Must never exceed 2000 amperes, even momentarily | |
| Minimum heating time at normal operating voltage before plate voltage is applied | 60 | s |
| Minimum time to reach operating voltage | 30 | s |
| Mu-Factor, Grid No.2 to Grid No.1 | 7 | |

Direct Interelectrode Capacitances:

| | | |
|---|---|---|
| Grid No.1 to plate | 2.0 | pF |
| Grid No.1 to grid No.2 and cathode | 1200 | pF |
| Plate to cathode and grid No.2 | 150 | pF |
| Grid No.2 to cathode | 15 | pF |

Electrical Circuit Protection:
Protection of all electrical circuits is required. For details, see Section V I.B, page 9, of Application Guide for RCA Super Power Tubes, ICE–279A.

**Mechanical:**

| | | |
|---|---|---|
| Operating Position | Tube axis vertical, either end up | |
| Overall Length | 18 | inches |
| Maximum Diameter | 14.5 | inches |
| Terminal Connections | See *Dimensional Outline* | |
| Weight (Approx.) | 80 | lbs |

**Thermal:**

| | | |
|---|---|---|
| Ceramic-Insulator Temperature | 150 max. | °C |
| Metal-Surface Temperature | 100 max. | °C |
| Minimum Storage Temperature, without cooling liquid in coolant ducts[a] | –65 min. | °C |
| External Gas Pressure[b] | 60 max. | psia |

For further information or application assistance on this device, contact your RCA Field Representative or write Super-Power Tube Marketing, RCA, Lancaster, Pa.



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ELECTRONIC COMPONENTS AND DEVICES

THIS INFORMATION APPLIES TO A CONTEMPLATED LABORATORY TUBE DESIGN AND IS SUBJECT TO CHANGE. NO OBLIGATIONS ARE ASSUMED AS TO FUTURE MANUFACTURE UNLESS OTHERWISE ARRANGED.



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## PROPOSED GENERAL DATA Cont'd.

**Air Cooling:**

It is important that the temperature of any external part of the tube not exceed the value specified. In general, forced-air cooling of the ceramic insulators and the adjacent contact areas may be required if the tube is used in a confined space without free circulation of air. Under such conditions, provision should be made for blowing an adequate quantity of air across the ceramic insulators and adjacent terminal areas to limit their maximum temperature to the value specified. Interlocking of the air flow with all power supplies is recommended to prevent tube damage in case of failure of adequate air flow.

**Liquid Cooling:**

Liquid cooling of the filament, cathode, grid No.1, grid No.2, and plate is required. When the environmental temperature permits, the coolant may be water; the use of distilled water or filtered deionized water is essential. The liquid flow must start before application of any voltages and preferably should continue for several seconds after removal of all voltages. Interlocking of the liquid flow through each of the cooled elements with all power supplies is recommended to prevent tube damage in case of failure of adequate liquid flow.

**Flow:**

Liquid Pressure at any inlet . . . . . . . . . 100 max. psi

Water Flow:

| | *Typical Flow* | *Max. Pressure Differential for Typical Flow*[c] |
|---|---|---|
| | *gpm* | *psi* |
| To filament | 1.5 | 23 |
| To Cathode Coolant Assembly | 1.5 | 23 |
| To grid No.1 | 1.5 | 23 |
| To grid No.2 | 1.5 | 23 |
| To plate | | |
| For plate dissipations up to 50 kW (Av.) | 20 | 7 |
| For plate dissipations of 50 kW to 150 kW (Av.) | 40 | 25 |
| For plate dissipations of 150 kW to 250 kW (Av.) | 65 | 60 |

Resistivity of Water at 25°C . . . . . . . 1 min. megohm-cm

Water Temperature from any outlet . . . 70 max. °C

## FOOTNOTES

*for Proposed General Data and Proposed Ratings*

[a] The tube coolant ducts must be free of water before storage or shipment of the tube to prevent damage from freezing.

[b] This pressure is related to the output-cavity pressurization as required to prevent corona or external arc-over.

[c] Measured directly across cooled element for the indicated typical flow.

[d] See Section V.C of 1CE-300.

[e] Refer to 1CE-279A for definitions.

[f] The magnitude of any spike on the plate voltage pulse should not exceed the peak value of the plate voltage pulse by more than 4000 volts, and the duration of any spike when measured at the peak-value level should not exceed 10% of the maximum "ON" time. The output circuit may require pressurization to prevent corona or external arc-over at the ceramic insulator.

[g] The magnitude of any spike on the grid-No.2 voltage pulse should not exceed the peak value of the grid-No.2 voltage pulse by more than 250 volts, and the duration of any spike when measured at the peak-value level should not exceed 10% of the maximum "ON" time.

[h] A negative dc voltage of 300 volts maximum may be applied to grid No.2 to prevent any tube conduction between pulses.

[i] The grid-No.1 voltage may be a combination of fixed and self bias obtained from a series grid resistor.

[k] The magnitude of any plate voltage spike shall not exceed 60 kilovolts (referenced to the cathode), and the duration of any spike when measured at the dc level shall not exceed 5 microseconds. Pressurization may be required to prevent external tube circuit arcing.

## PROPOSED RATINGS

### RF POWER AMPLIFIER[d] - Class C Telegraphy

### and

### RF POWER AMPLIFIER[d] Class C FM Telephony

**Maximum CCS Ratings, *Absolute-Maximum Values:***

| | *Up to 50 Mc/s* | |
|---|---|---|
| DC PLATE VOLTAGE | 25 max. | kV |
| DC GRID-No.2 VOLTAGE | 1500 max. | V |
| DC GRID-No.1 VOLTAGE | –400 max. | V |
| DC PLATE CURRENT | 50 max. | A |
| PLATE DISSIPATION* | 250 max. | kW |
| GRID-No.2 DISSIPATION* | 5.0 max. | kW |
| GRID-No.1 DISSIPATION* | 500 max. | W |

* Determined by calimetric measurements.

**Typical CCS Operation:**

| | *At 30 Mc/s* | |
|---|---|---|
| DC Plate Voltage | 20 | kV |
| DC Grid-No.2 Voltage | 1200 | V |
| DC Grid-No.1 Voltage | –225 | V |
| Peak RF Grid-No.1 Voltage | 250 | V |
| DC Plate Current | 38 | A |
| DC Grid-No.2 Current | 3.8 | A |
| DC Grid-No.1 Current | 1.2 | A |
| Driver Power (Approx.) | 260 | W |
| Circuit Efficiency (Approx.) | 95 | % |
| Useful Power Output (Approx.) | 500 | kW |

## PROPOSED RATINGS Cont'd.

## PLATE-MODULATED RF POWER AMPLIFIER - Class C Telephony

*Carrier conditions per tube for use with a max. modulation factor of 1.0 unless otherwise indicated.*

**Maximum CCS Ratings, *Absolute-Maximum Values:***

| | Up to 50 Mc/s | |
|---|---|---|
| DC PLATE VOLTAGE | 20 max. | kV |
| DC GRID-No.2 VOLTAGE | 1200 max. | V |
| DC GRID-No.1 VOLTAGE | –400 max. | V |
| DC PLATE CURRENT | 30 max. | A |
| PLATE DISSIPATION* | 165 max. | kW |
| GRID-No.2 DISSIPATION* | 2.5 max. | kW |
| GRID-No.1 DISSIPATION* | 500 max. | W |

**Typical Operation:**

| | At 30 Mc/s | |
|---|---|---|
| DC Plate Voltage | 17.5 | kV |
| DC Grid-No.2 Voltage | 1000 | V |
| DC Grid-No.1 Voltage | –225 | V |
| Peak RF Grid-No.1 Voltage | 250 | V |
| DC Plate Current | 26 | A |
| DC Grid-No.2 Current | 2.6 | A |
| DC Grid-No.1 Current | 1.2 | A |
| Driver Power Output (Approx.) | 260 | W |
| Output-Circuit Efficiency (Approx.) | 95 | % |
| Useful Power Output (Approx.) | 300 | kW |

## PULSED RF AMPLIFIER[d]

*For frequencies up to 50 Mc/s and a maximum "ON" time[e] of 2500 µs in any 40,000-microsecond interval.*

**Maximum Ratings, *Absolute-Maximum Values:***

| | | |
|---|---|---|
| PEAK POSITIVE-PULSE PLATE VOLTAGE[f] | 40 max. | kV |
| PEAK POSITIVE-PULSE GRID-No.2 VOLTAGE[g,h] | 2000 max. | V |
| DC OR PEAK NEGATIVE-PULSE GRID-No.1 VOLTAGE | 400 max. | V |
| PEAK PLATE CURRENT | 60 max. | A |
| PEAK GRID-No.2 CURRENT | 10 max. | A |
| PEAK RECTIFIED GRID-No.1 CURRENT | 4 max. | A |
| DC PLATE CURRENT | 3.6 max. | A |
| DC GRID-No.2 CURRENT | 0.6 max. | A |
| DC GRID-No.1 CURRENT | 0.24 max. | A |
| PLATE DISSIPATION (AVERAGE)* | 50 max. | kW |

**Typical Plate-Pulsed Operation:**

*In Class B service at 30 Mc/s with a rectangular waveshape pulse.*

*Pulse width[e]:* 2000 µs
*Duty factor[e]:* 0.06

| | | |
|---|---|---|
| Peak Positive-Pulse Plate Voltage[f] | 35 | kV |
| Peak Positive-Pulse Grid-No.2 Voltage[g] | 1800 | V |
| Peak Negative-Pulse Grid-No.1 Voltage[i] | 260 | V |
| Peak Plate Current | 50 | A |
| Peak Grid-No.2 Current | 5.0 | A |
| Peak Rectified Grid-No.1 Current | 2 | A |
| DC Plate Current | 3 | A |
| DC Grid-No.2 Current | 0.3 | A |
| DC Grid-No.1 Current | 0.12 | A |
| Peak Driver Power Output (Approx.) | 640 | watts |
| Output Circuit Efficiency | 95 | % |
| Useful Peak Power Output | 1200 | kW |

## HARD-TUBE PULSE MODULATOR SERVICE[d]

*For a maximum "ON" time of 2500 microseconds in any 40,000-microsecond interval.*

**Maximum Ratings, *Absolute-Maximum Values:***

| | | |
|---|---|---|
| DC PLATE VOLTAGE[k] | 55 max. | kV |
| DC OR PEAK POSITIVE-PULSE GRID-No.2 VOLTAGE | 2000 max. | V |
| DC GRID-No.1 VOLTAGE | –500 max. | V |
| PEAK POSITIVE-PULSE GRID-No.1 VOLTAGE | 100 max. | V |
| PEAK PLATE CURRENT | 230 max. | A |
| DC PLATE CURRENT | 14 max. | A |
| PEAK GRID-No.2 CURRENT | 20 max. | A |
| PEAK GRID-No.1 CURRENT | 16 max. | A |
| PLATE DISSIPATION (AVERAGE)* | 50 max. | kW |

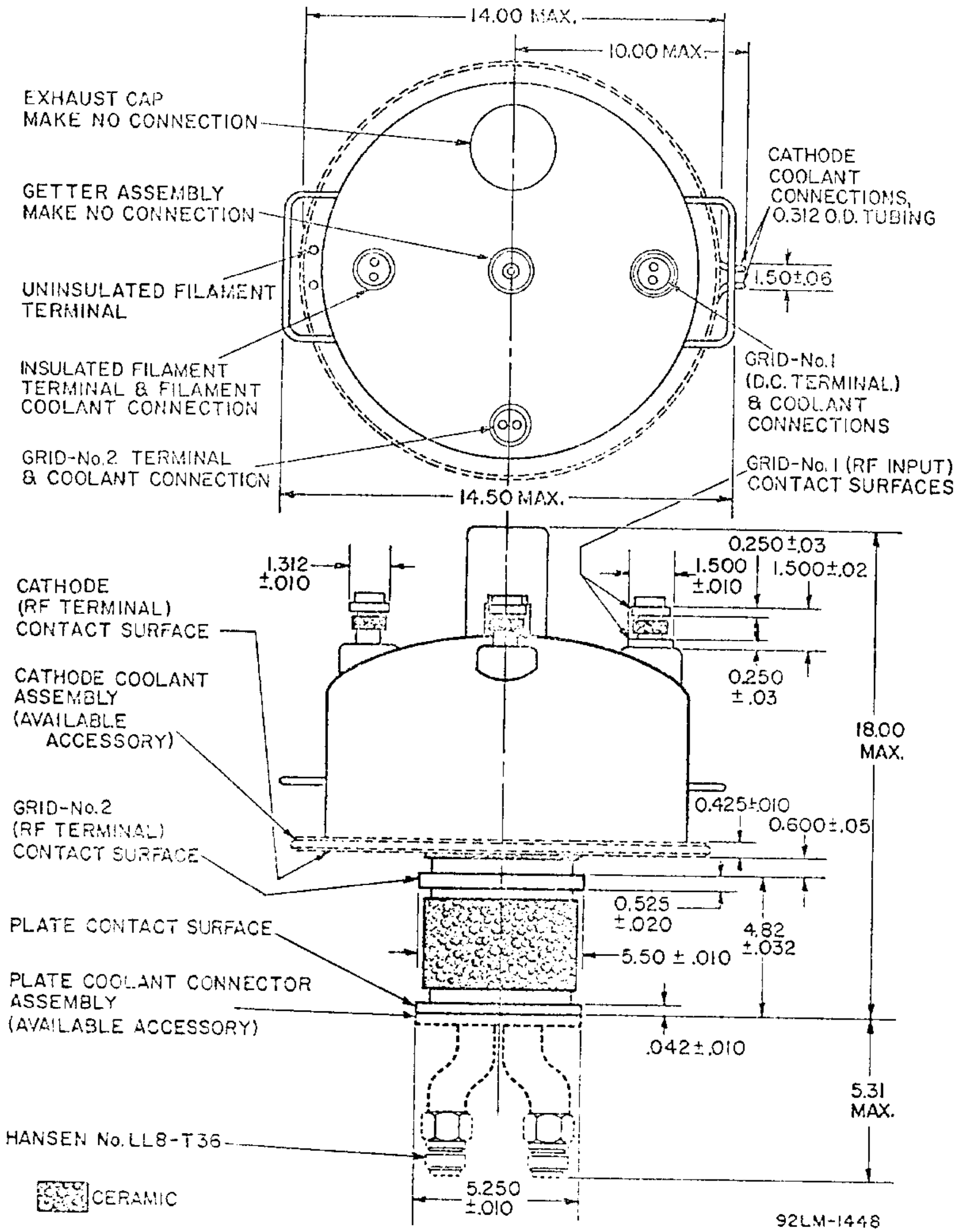
**Typical Operation:**

*With rectangular waveshape pulses, duty factor of 0.04 and pulse duration of 1600 microseconds.*

| | | |
|---|---|---|
| DC Plate Voltage | 50 | kV |
| Peak Grid-No.2 Voltage | 1800 | V |
| DC Grid-No.1 Voltage | –350 | V |
| Peak Positive Grid-No.1 Voltage | 50 | V |
| Peak Plate Current | 220 | A |
| DC Plate Current | 8.8 | A |
| Peak Grid-No.2 Current | 12 | A |
| Peak Grid-No.1 Current | 12 | A |
| Load Resistance | 207 | ohms |
| Useful DC Power Output at Peak of Pulse | 10 | MW |

*Determined by calorimetric measurements.

PROPOSED DIMENSIONAL OUTLINE




DIMENSIONS IN INCHES